University of Trento

Department of Industrial Engineering
Master's Degree in Mechatronics Engineering

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Project of the course Mechanical Design for Mechatronics

An Automatic Cut&Split machine for firewood

Teacher
Prof. Emiliano Rustighi

Students

Alberto Andreetto	ID 267439
Leonardo Costanzi	ID 267342
Isacco Libera	ID
Paolo Rossi	ID
Daniele Trisotto	ID 267254

Abstract

Qui va l'abstract

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Introduction

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Chapter 2

General statement of the client

2.1 General statement of the client's dissatisfaction

The machines currently available on the market require the constant presence of an operator, are not very flexible, and are relatively slow in operation.

The machines currently available on the market are relatively slow in processing a log in input into the final chunk; not very flexible in terms of allowed log diameters in input (there is little possibility to change the diameter once the machine is switched on), and finally they need the presence of an operator in order for them to perform the process.

So, our goal is to try to fix these issues; in particular, the core of the project will be focused on automatizing the entire firewood processor and finding a solution that allows to adjust the working log diameter in real time.

2.2 Product design specification (PDS)

Table 2.1: Product Design Specification – Firewood Cut & Split Machine

N°	Product Design Specification	Value	R/D
1.	**Geometry**		
1.1	Input length of the log	$4^{+1}_{-3}\,m$	R
1.2	Maximum workable diameter of input log	$70^{+5}_{-5}\,cm$	R
1.3	Output length of firewood stick	$25^{+1}_{-1}\,cm$	R
1.4	Output geometry of firewood stick	Approximately parallelepiped	D
1.5	Mean output area of firewood stick	$60^{+20}_{-20}\,cm^2$	R
2.	**Kinematics**		
2.1	Easy and economic accessories substitution	Commercial standard parts	D
Cutting system			
2.21	Cutting time (Ø70 cm fir wood)	$15^{+2}_{-2}\,s$	D
2.22	Clamping force	$\geq$ saw force [N]	R
2.23	Clamping speed (to be included in cycle time)	As fast as possible [mm/s]	D

Continued on next page

Table 2.1 (continued)

N°	Product Design Specification	Value	R/D
2.24	Cycle until maintenance	To be defined after design	–
	Splitting system		
2.31	Splitting speed	130^{+20}_{-20} mm/s	D
–	Splitting time (alternative to speed)	-	–
2.32	Return speed	As fast as possible [mm/s]	D
2.33	Splitting force	$150000^{+\infty}_{-0}\,N$	R
–	Max wood density (alternative to force)	-	–
–	Cycle until maintenance	To be defined after design [#cycles]	–
	Input feeding system		
2.41	Advancement speed	26^{+10}_{-2} cm/s	R
2.5	Cycle time	As short as possible [s]	D
2.6	Production rate	10^{+5}_{-2} m^3/h	D
3.	**Energy**		
3.1	Power supply	Three-phase $480\,V, 50\,Hz$	R
4.	**Material**		
4.1	Environmental resistance	To be confirmed with supervisor	D
4.2	Shock resistance of input feeding system	Horizontal fall from 1 m of Ø70 cm log without yielding	R
6.	**Terms of Use**		
6.2	Fully automatic	–	D
6.21	Number of human actions after being loaded	0^{+0}_{-0}	R

Sources

- https://wolferidgemfg.com/product/japa-505-pro-firewood-processor/
- https://cordking.ca/products/cs-series-log-processor/
- https://www.dyna-products.com/firewood-processors/
- https://forestnet.com/tech-review-firewood-processors/
- https://bilthardusa.com/pages/how-many-tons-of-force-do-you-need-in-a-log-splitter/
- https://www.saettastore.it/13-combinate

Chapter 3

Concept Selection

Although the project focuses mainly on the splitting stage, several possible concepts for the overall Cut&Split machine are presented below. In particular, the system can be divided into the following subsystems:

- Input Feeding System;
- Retaining System;
- Cutting System;
- Split Actuator System.

3.1 Input Feeding System

The aim of this first stage is to load the machine with a workable log. To achieve this, two alternative approaches are proposed:

- A set of toothed rollers, where one roller is directly driven by a motor while the remaining rollers are actuated through a chain transmission (Figure 3.1);
- A chain conveyor equipped with teeth to ensure adequate grip on the log, with the chain tensioned between a drive and a driven pinion (Figure 3.2).

Figure 3.1: Toothed rollers

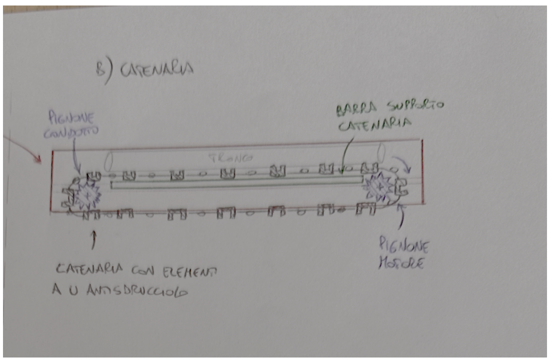

Figure 3.2: Chain conveyor

3.2 Retaining System

In order to stabilize the log during the cutting stage of the process, a retainer system is needed. Two possible designs are presented here:

- a toothed roller retainer (Figure 3.3), which is a smaller dimension-version of the toothed roller previously presented. At this stage however, it is mounted on a fixed arm with a set of springs; the aim is pushing the log against the ground to stabilize it while the cut occurs. This mechanism allows different log's diameters because it adapts to different heights instantaneously;

- a retainer arm (Figure 3.4), which is the most used system nowadays. This mechanism also allows different diameters, but it has a higher positioning time compared to the previous one, since it requires an external actuator to complete this task.

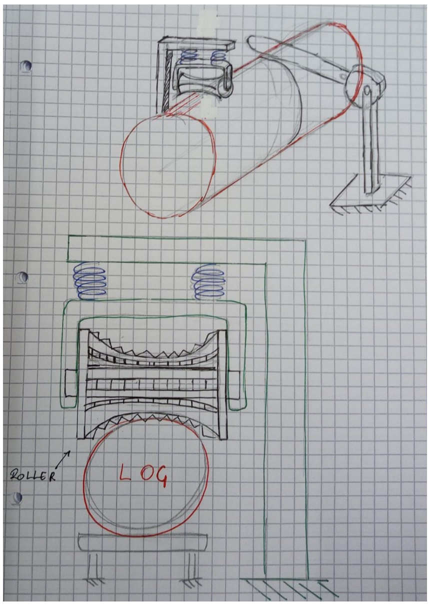

Figure 3.3: Toothed roller retainer

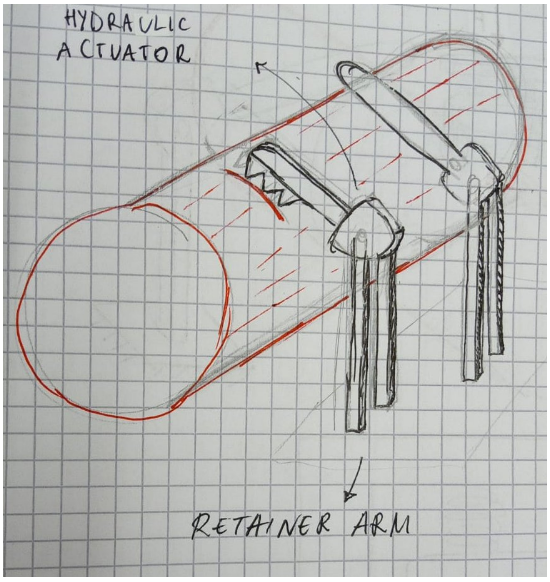

Figure 3.4: Retainer arm

3.3 Cutting System

In order to cut the log into small chunks, a cutting system is required. Two concepts are proposed:

- A chainsaw bar that moves around a pivot (Figure 3.5);

- A circular saw that moves with liner and horizontal motion (Figure 3.6).

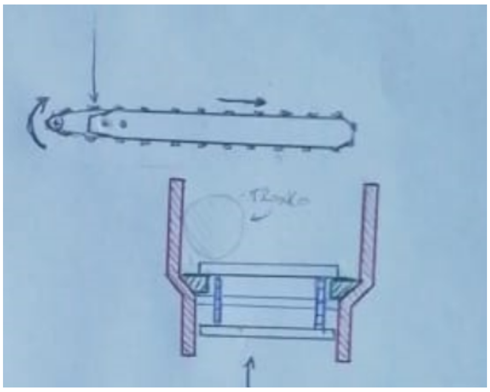

Figure 3.5: Chainsaw sketch

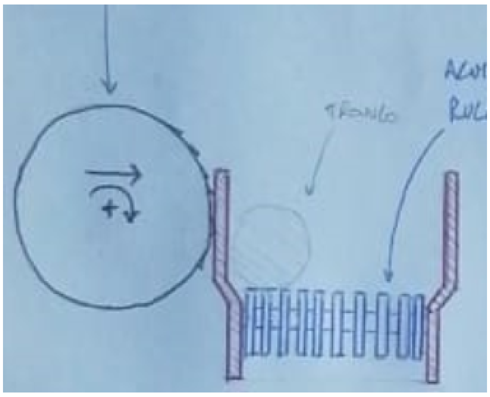

Figure 3.6: Circular saw sketch

3.4 Splitting system

This part of the overall system is the main aim of our design, as previously stated. The task of this subsystem is to split the wood chunks into small pieces of firewood. Four concepts are developed; here we briefly explain the most important features and then, with aid of a decision matrix, we will choose the most suitable one.

3.4.1 Vertical motion with hydraulic cylinder

In this system (Figure 3.7), a conveyor belt moves the wood chunks forward. In order to split chunks, they must have the flat surface resting on the belt; thus, an overturning system is necessary to ensure the correct positioning of the chunks. A hydraulic cylinder actuates the mask, which is shaped in a cross shape. Several squeezes are necessary to completely split a chunk, but resulting shapes are mainly parallelepipeds with constant cross-area. When the cylinder is moving, the belt must remain still.

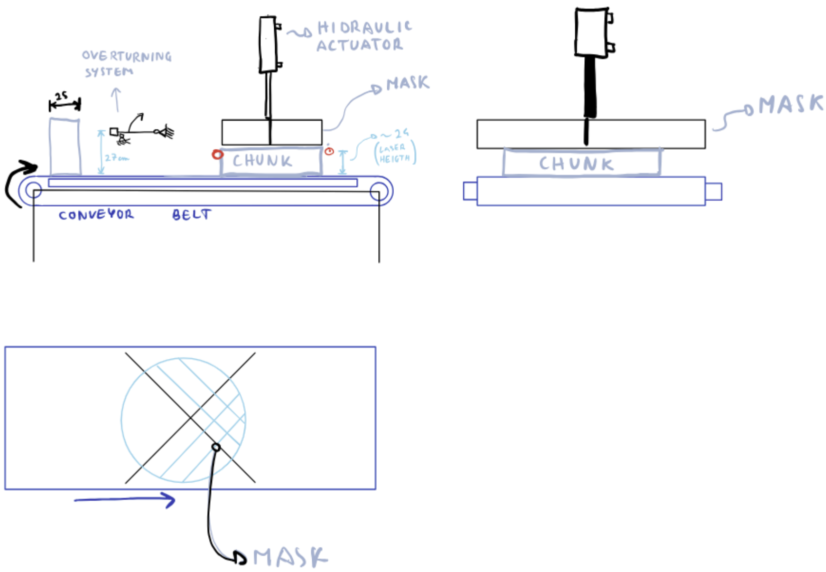

Figure 3.7: Sketch of the Concept 1

3.4.2 Vertical motion with lever mechanism

This system (Figure 3.8) is quite similar to the previous one, however, instead of using a hydraulic cylinder, a mechanical mechanism is used. This results in a faster system then the previous one, because the belt can also continue his motion during the split time. Moreover, for that reason, it requires less mechatronics control.

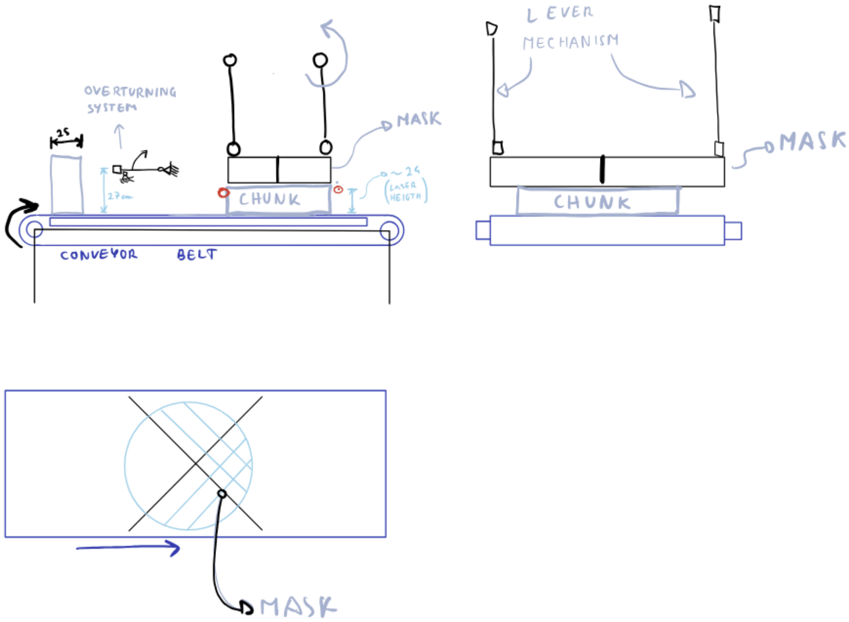

Figure 3.8: Sketch of the Concept 2

3.4.3 Alternate motion with bidirectional mask

This system (Figure 3.9) consists of a mask that can cut in both directions. The mask is moved by four power screws. When the chunk is split, the bottom of the system opens in order to unload the pieces of firewood. This system could be quite fast because it reduces dead times but the resulting shapes aren't really constant and even.

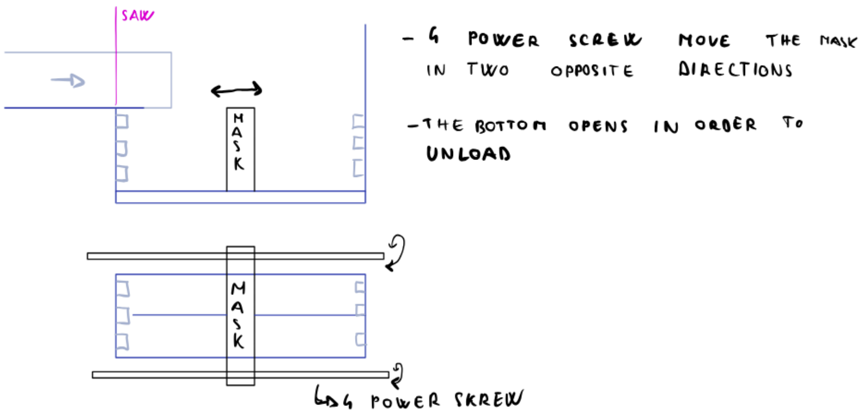

Figure 3.9: Sketch of the Concept 3

3.4.4 Traditional splitting system with translating mask

This system (Figure 3.10) is the most traditional, but instead of using a fixed mask as in the product currently in the market, a different mask rack is used. This can move up and down and ensures constant and even dimensions of the final product.

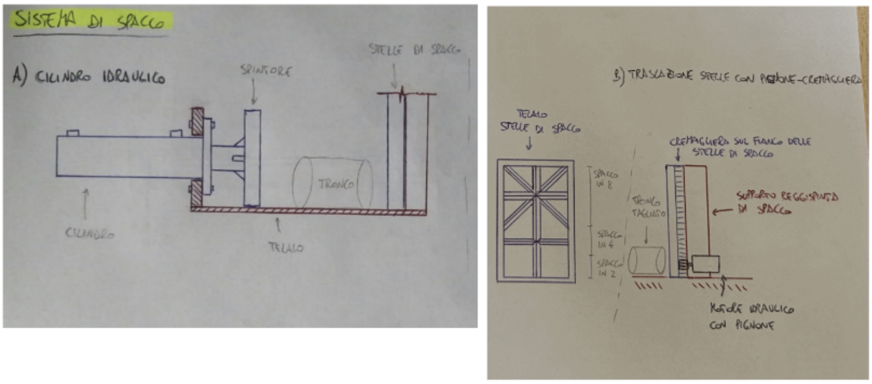

Figure 3.10: Sketch of the Concept 4

3.4.5 Concept evaluation with Decision Matrix

To support the selection of the most suitable concept for the splitting system, a decision matrix was developed to compare the four proposed design alternatives in a structured and quantitative manner. Each concept was evaluated against a set of criteria identified as relevant for the intended application, including processing time, reliability, flexibility of the output shape, and the range of acceptable workpiece dimensions.

Since several of these criteria are qualitative in nature, a qualitative-to-numeric conversion table (Table 3.1 was adopted to ensure consistency across evaluations. The qualitative levels ("Great", "Good", "Okay", "Fair", "Poor") were mapped to numerical scores ranging from 10 to 2, allowing them to be integrated into the weighted scoring process of the matrix. This approach ensures that both objective measurements and subjective engineering judgments contribute transparently to the final assessment.

Qualitative Level	**Numeric Score**
Great	10
Good	8
Okay	6
Fair	4
Poor	2

Table 3.1: Qualitative-to-numeric conversion table used in the Decision Matrix.

The results of the decision matrix (Table 3.2) indicate that Concept 1 (vertical motion with hydraulic cylinder) provides the best trade-off between performance, reliability, and operational flexibility, therefore suggesting it as the preferred design option.

Comparison Block 1: Vertical Motion Concepts

Objective	**Weight Factor**	**Parameter**	**Vertical: Hydraulic Cylinder**			**Vertical: Lever**		
			Mag	Score	Value	Mag	Score	Value
Time for splitting 70cm chunk	0.20	s	24	1	0.20	24	1	0.20
Likeness to parallelepiped shape	0.05	Qualitative	Good	8	0.40	Good	8	0.40
Envelope dimensions	0.05	m×m×m	0.9×1.2×0.9	3	0.20	0.9×1.2×3	1	0.10
Reliability	0.15	Experience	Great	10	1.50	Poor	2	0.30
Output shape flexibility	0.35	Qualitative	Great	10	3.50	Good	8	2.80
Flexibility on processable diameters	0.10	cm	10	5	0.50	10	5	0.50
Flexibility on processable lengths	0.10	cm	5	1.5	0.20	10	3	0.30
Overall value	**1**	–			**6.3**			**4.5**

Comparison Block 2: Alternative Splitting Concepts

Objective	**Weight**	**Parameter**	**Bidirectional Mask**			**Translating Mask**		
			Mag	Score	Value	Mag	Score	Value
Time for splitting 70cm chunk	0.20	s	3	8	1.60	4	6	1.20
Likeness to parallelepiped shape	0.05	Qualitative	Fair	4	0.20	Fair	4	0.20
Envelope dimensions	0.05	m×m×m	0.75×0.75×0.3	15	0.80	0.75×0.75×0.3	15	0.80
Reliability	0.15	Experience	Okay	6	0.90	Great	10	1.50
Output shape flexibility	0.35	Qualitative	Poor	2	0.70	Okay	6	2.10
Flexibility on processable diameters	0.10	cm	2	1	0.10	2	1	0.10
Flexibility on processable lengths	0.10	cm	3	0.9	0.10	3	0.9	0.10
Overall value	**1**	–			**3.8**			**5.4**

Table 3.2: Split System Decision Matrix

Chapter 4

Core specification Selection

To do so, we built a small dataset collecting with other manufacturers data and then, using a simple linear polynomial fit, we interpolated it with our dimensions in order to have our splitting force target.

Table 4.1: Manufacturers data used to interpolate our splitting force target

Manufacturer	**Maximum log diameter (mm)**	**Maximum log length (mm)**	**Maximum splitting force (kN)**
Rabaud	800	500	143
Varimatic	300	550	62.3
Brugger	500	600	267
FuelWood	800	1000	151
Bizon-Ins	380	550	142
Amix	450	550	133

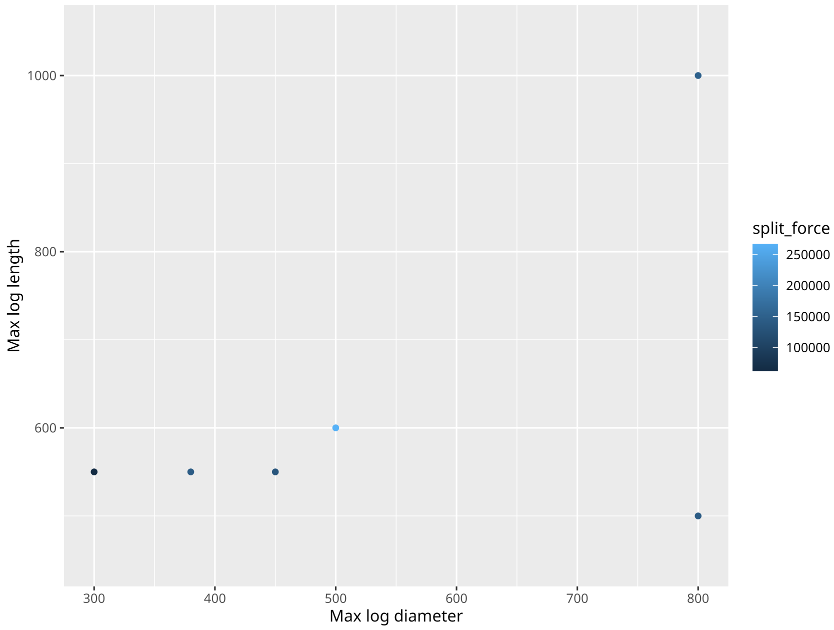

Figure 4.1: Collected data from other manufacturers to evaluate our splitting force

Based on that, and using the following code in **RStudio**

```
data.lm <- lm(split_force ~ poly(max_d, 1, raw = T) + poly(max_l,
    1, raw = T), data = df)
summary(data.lm)
df %>%
  add_predictions(data.lm)

our_chunk <- tibble(
  max_d = 700,
  max_l = 250
)
predict(data.lm, newdata = our_chunk)
```

our splitting force resulted in
Splitting force = 166 kN

Chapter 5

Conclusion